Energy and exergy analysis of alumina–water nanofluid for an electronic liquid cooling system

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ABSTRACT

Energy and exergy analysis of a rectangular shape minichannel heat sink is experimentally performed using nanofluid as coolants. The Al2O3-water nanofluid with nanoparticle concentrations of 0.10 to 0.25 vol.% were used as coolants to analyze the effect of changing the flow rate ranging from 0.375 to 1.0 l/min. The highest energy efficiency was found to be 94.88% for 0.25 vol.% of Al2O3-water nanofluid and flow rate of 0.375 l/min. The highest improvement of overall exergy (60.88%) of the heat sink was obtained for Al2O3-water nanofluid at 0.25 vol.% compared to water at the flow rate of 1.0 l/min. The exergy gain increased accordingly with the increase in the volume fraction of nanoparticles and decreased with the rise of flow rate. The highest exergy gain was found at 0.25 vol.% of nanofluid. The second law efficiency (exergy efficiency) found to be augmented with the rise of the volume fractions of nanofluid. The friction factor decreased with the augmentation of flow rate and increased with the rise of the volume fractions of nanoparticles.

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1. Introduction

Recently, the integration and compaction of electronics chips have risen to a high level with the need to offer more processing power than ever before [1,2]. Thermal management of electronic components has gained a lot of attention due to the drastic increase in transistor density, decrease in feature size, and enhancement in computation speeds leading to high heat fluxes [3]. The cooling demands of next generation 3D integrated chip designs also cause inevitable switching to liquid cooling systems [4]. For cooling of electronic devices, nanofluids have been proposed to be high performance coolants [5]. During the last decades, it is proven through the different experimental, analytical, and numerical investigations that, nanofluids perform well when used for cooling of electronics.

Nanofluid is a new type of heat transfer fluid, which was termed after the innovative studies by Choi [6]. Nanofluid is a mixture of solid nanoparticles into a base fluid. Nanoparticles that are used to prepare nanofluids are basically metal (Cu, Al, etc.), oxides (Al2O3, TiO2, CuO, SiO2, etc.) and some other compounds (CNT, TNT, graphene, etc.) and base fluids usually include water, ethylene glycol, refrigerant, engine oil, and others. Due to the extremely small sizes and large specific surface areas of the nanoparticles, nanofluids have superior properties like high thermal conductivity, minimal clogging in flow passages, long-term stability, and homogeneity compared with base fluids.

Characteristics of nanofluids like stability and thermophysical properties are the performance indicators in a heat transfer system like minichannel.

Tuckerman and Pease [7], report that a micro channel heat sink is an ideal tool for liquid cooling of electronic chips, as the heat transfer coefficient contrary with the characteristics of channel width in a laminar flow. They measured a maximum power dissipation density of 790 W/cm² with a thermal resistance of 0.1 °C cm²/W. Also they found a significant pressure drop of 2 bars for this investigation. Nguyen et al. [8] experimentally found up to 40% increase in the heat transfer coefficient for the case of Al2O3-water nanofluid compared to the pure base fluid. Chein and Huang [9] study on silicon microchannel heat sink performance using Cu-water nanofluid. They show that performance of the heat sink greatly improved due to the increase of thermal conductivity and thermal dispersion effect. Rafati et al. [10] investigated cooling of a computer microchip by using silica, alumina, and titania nanoparticles suspended in water and ethylene glycol mixture. They obtained the highest decrease in processor temperature (from 49.4 °C to 43.9 °C) for 1.0 vol.% of alumina nanofluid at a flow rate of 1.0 l/min. Putra et al. [11] applied nanofluids in a heat pipe liquid-block combined with thermoelectric cooling and the results showed significant improvement of heat transfer for Al2O3-water nanofluids. A number of researchers numerically studied nanofluids used as coolants in micro channel heat sinks [12-15]. Besides, many